CURRENT BALANCE

Purpose:

This lab should help you to "understand" the definition of the ampere by experimentally verifying Eq. (2) below. The **ampere** is that constant current which, if maintained in two long straight parallel wires placed one meter apart in vacuum, would produce on each of these conductors a force per unit length of 2×10^{-7} N/m.

Apparatus:

Variable low-voltage AC power supply (Variac and transformer)
Current balance apparatus
Laser
Set of milligram weights
AC ammeter
Connecting wires (ALREADY WIRED...**DO NOT** CHANGE!!)
Vernier Calipers
2-meter stick
Mac computer with gold PHYSICS DEPARTMENT INTERFACE BOX

Reference:

Tipler, fourth edition, pp 885-896.

Background:

In this experiment, you will use the expression for the magnetic force F_{mag} between two current-carrying parallel wires with axes separation *r*. The current I_1 in wire 1 produces a magnetic field $\vec{B}_1$ at the location of wire two, where

$$B_1 = \frac{\mu_0}{2\pi}\frac{I_1}{r} \qquad \text{so} \qquad \vec{F}_{mag,2} = I_2\vec{\ell} \times \vec{B}_1 \tag{1}$$

Our apparatus is arranged so that the two currents have same magnitude, with $I_1 = I_2 = I$, so that Equations (1) give us

$$F_{mag} = \frac{\mu_0}{2\pi} I^2 \frac{\ell}{r} \tag{2}$$

The apparatus we will use today is arranged with the currents in *opposite* directions, so the wires ***repel*** each other. This repulsion is explained in the textbook, on page 885-886.

We will measure F_{mag} and I for a range of values of I, keeping r and ℓ constant. Then we will make a graph of F_{mag} vs. I^2. The graph should be a straight line, and from its slope you are to verify that $\mu_0/(4\pi) = 10^{-7}$ N/A^2.

SAFETY NOTE: The voltage we are using today is "stepped-down" by the Variac and the transformer to a range of values that are safe to handle. Voltages are much higher on the input side of the transformer and Variac (the input is 120 V,) but the wires and connections are well insulated. If any of this insulation appears damaged or inadequate, notify your instructor.

LASER SAFETY: The lasers we are using today are "Class 2". For this class, the normal human aversion response—blinking, or looking away—is fast enough to protect your eyes. It could, therefore, be reasonably said that the only way you could hurt yourself with these LASERs would be to "poke yourself in the eye with it or to drop it on your foot."

Nevertheless, it is a good idea to observe the basic safety rule: *Never look into a laser beam*, and do not endanger any one else by shining it into their eyes. We will treat all LASERs in a manner parallel to the "loaded gun" approach. Additionally, while not strictly necessary with these LASERs, we will avoid introducing "shiny objects" (such as rings, bracelets, and eye-glasses) into the beam which may cause specular (rather than diffuse) reflection!

Procedure:

1. Examine the apparatus and see that it consists of a *balance*, which is movable, supported above a fixed *base* by means of *knife edges* which rest on *flats* so that the balance pivots on the knife edges. Fig. 1 is a schematic of the apparatus.

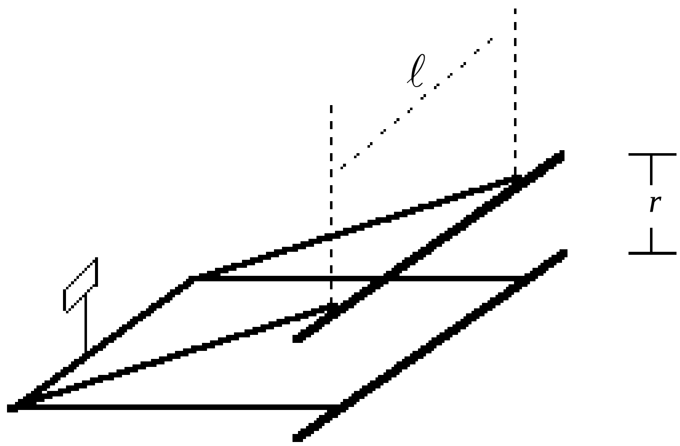

Figure 1. Schematic of the current balance.

2. Next, measure **and record** $\boldsymbol{\ell}$, the length of the upper front bar measured from center to center of the side bars to which it is attached (see Fig. 2.) It is a good idea to make this measurement at least twice, in order to detect any gross errors and to get an idea of the uncertainties.

3. We will now establish the equilibrium position of the balance. Be sure that the knife edges of the balance are centered on the respective flats so that the *damping vane* swings freely between the poles of the magnets in the base. Also, the upper front bar of the balance should be directly above and parallel to the fixed lower bar. To ensure this, press the top bar down onto the lower bar, then squeeze both bars horizontally near their ends between the thumb and forefingers of both hands. This may cause the knife edges to slide on their flats, and they should end up near the center of the flats. If they don't, adjust the lengths of the *side bars* of the balance by loosening the set screws which hold them. *Be sure to tighten them again!* The bars should also be parallel in the vertical plane, so that when the bars touch, they touch along their entire lengths. If this is not the case, tell your instructor, who can bend the bars slightly until parallelism is achieved.

Having done this, use the vernier calipers as outside calipers, and measure and record the diameters, D_1 and D_2 of the bars. From these values, calculate and record the radii of the two bars. Then use the calipers, this time as inside calipers, to measure inside separations, adjust the counterweights at the back of the apparatus (behind the mirror) so that the distance between the bottom of the top wire and the top of the bottom wire is about 4 mm in equilibrium. This is the distance s in Fig. 2. From this, compute r, the distance between the axes of the two front bars. Record the result.

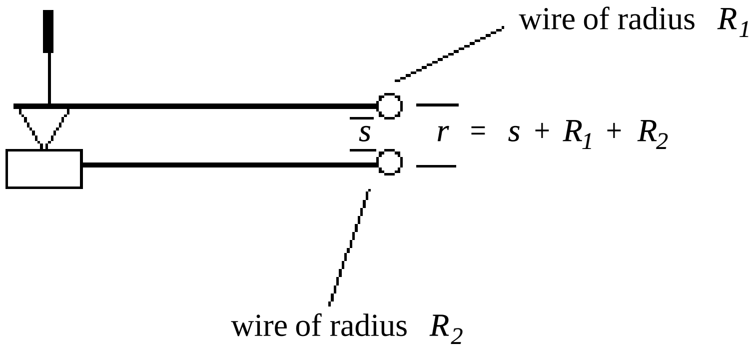

Figure 3. A side view of the apparatus.

Recheck that the entire apparatus moves freely!! Then, MAKE NO MORE ADJUSTMENTS UNTIL YOU HAVE FINISHED TAKING THE DATA.

4. Next, turn on the laser and shine the beam on the mirror in such a way that it reflects off the mirror and strikes the blackboard or wall making a red dot. If it is on the blackboard, make a chalk circle around the edges of the dot. If it is on the wall, tape a piece of paper on the wall and draw a circle around the dot. Once you have finished, **do not move the laser until you have finished taking your data. The center of your circle is the equilibrium position of the dot.**

5. Use the tweezers to take a 20 mg (milligram) mass from your boxed set of weights and put it on the pan on the upper front bar. (You may assume these are accurate to ± 0.05 mg — the use of the tweezers is meant to KEEP them that way!!) The laser beam will be displaced downward from the equilibrium position. Turn the dial of the Variac all the way down so you don't get an unexpected surge of current, and then turn it on. Now use the dial to adjust the current until the balance is back to its equilibrium position. Record the current, I.

6. Repeat step 5 for larger masses at 20-mg intervals, each time recording the current and the mass M of the weights. Do this until the current required to balance the weight of the mass is about 13 A. **DO NOT go above 15 A on the meter. Please turn the current off when you have finished taking the data.**

7. Each time you return the balance to equilibrium, the **weight,** Mg, of all the masses on the upper bar is balanced by the magnetic force, so the magnetic force is equal to Mg. Make a graph of M vs. I^2. From the slope, calculate the measured value of $\mu_0/(4\pi)$. Show the calculation and compare the result with the defined value of 10^{-7} T·m/A. State the percent error between your value and the defined value, treating the defined value as a standard.

8. If the defined value of $\mu_0/4\pi$ is assumed to be 10^{-7} T·m/A, today's laboratory exercise could be considered as a method of calibrating the ammeter. Explain.

9. The biggest sources of error in this experiment are ℓ, s, and I. The ammeter isn't very accurate. Discuss the effect errors in each of these would have on $\mu_0/4\pi$. For example, how large (or small) would s have to be in order to explain your error? Is the needed value of s reasonable? By what percentage would the ammeter have to be off? And so on.

BE SURE to turn in your raw data and all your print-outs as part of your lab report.